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DISCUSSION ARTICLE

Home heating in temperate Australia

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Abstract
Background, aim, and scope Home heating is an important component of life in inland temperate Australia, and firewood remains a common and relatively inexpensive fuel. However, supplies of firewood are becoming scarce, and excessive smoke pollution is becoming a problem in some places, partly due to poor management of fires. The alternative energy sources are electricity and gas, and the aim of this study is to compare the relative merits of these three energy sources for their impacts on the physical environment.
Materials and methods Data were compiled about the physical appliances used in the home for electric power, and for gas and wood burning. Data about the production of electricity, gas supply and burning was available in Australian databases. The inputs and outputs for the growing of firewood in plantations in the drier, cooler parts of inland Australia were compiled from various sources and supplemented by measurements of typical tree growth. Information about emissions from wood burning was obtained from several sources, and all data were entered into SimaPro life cycle assessment software. The Eco-Indicator 99 (E) method was then used to assess the impacts of a range of heating scenarios including two different gas heaters, three different wood burners and a variety of wood growth rates and burning conditions.
Results Overall results show that, as expected, using coal-fired electricity for heating had a significantly larger impact than the other forms of heating. The older, less efficient wood burning appliances were also significantly inferior to modern appliances mainly because of their inefficiency. There was a significant lessening of impact when wood was burned in a modern appliance under well-managed conditions compared to poor management. The comparison between gas and wood burning showed significant advantages for each with wood being preferable from a resource and climate change perspective, and gas being preferred from a health and ecological perspective.
Discussion The results suggest that using electricity for heating should be discouraged as should the use of inefficient, older, wood burning appliances. The impact of wood burning depends very much on how fires are managed but is acceptable and could make a major contribution to reducing carbon dioxide emissions if users can be educated to reduce emissions by managing fires better. Sufficient firewood could be grown on plantations even though the rate of growth is slow but would require a significant area of land. The big advantage of doing this is that wood is a renewable resource. So the two alternative heating sources at the moment are gas and wood burning, and the decision about which to use will depend on the ability to reduce emissions from wood.
Recommendations and perspectives It is recommended that electricity use for heating be discouraged in the future and that gas be considered as an alternative, at least in the short term, while we depend on coal burning to produce electricity. Wood should continue to be used, but more community education about managing fires is needed as is a move towards growing firewood on plantations.

Keywords Electric heating · Eucalypt growth rates · Firewood emissions · Firewood plantations · Gas burning · Home heating · Sustainability of supply · Wood burning

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1 Background, aim, and scope

Eastern Australia is characterized geographically by a relatively narrow coastal strip where the climate is moderated by the low elevation, proximity to the sea and relatively high rainfall, plus an inland area separated from the above area by the Great Dividing Range. This area has a temperate climate over about the southern two thirds of its length and is considerably drier and colder in the winter than adjacent coastal areas due to its elevation and the impact of the mountain range. There are also areas of similar climate in the island state of Tasmania and in the southwest of the continent as shown in Fig. 1. Consequently, there is a need for home heating for at least several months of the year. Heating is typically single-room heating. The population density is not high due to the dry climate although the areas are highly productive agriculturally.

In these areas, there is a strong cultural tradition of using wood for home heating because of the once abundant eucalypt trees. However, this source of energy is now declining as land is cleared and experts consider the current rate of wood use to be unsustainable (Driscoll et al. 2000). Electricity has become a major source of heating energy with both dedicated electric radiators and built-in air conditioners being now common. Free-standing gas burning heaters are also common, but heaters that burn petroleum products such as heating oil or kerosene are no longer popular.

The major current issue in relation to heating is the climate change impact, and Fig. 2 shows the amount of carbon dioxide equivalent released by the burning of various fuels in Australia. From a climate change point of view, firewood is better for heating than other nonrenewable sources of energy such as gas or electricity, provided it is burnt in a modern, highly efficient, wood burner and so its continued use is worth considering. For this study, only wood, electricity and gas will be considered.

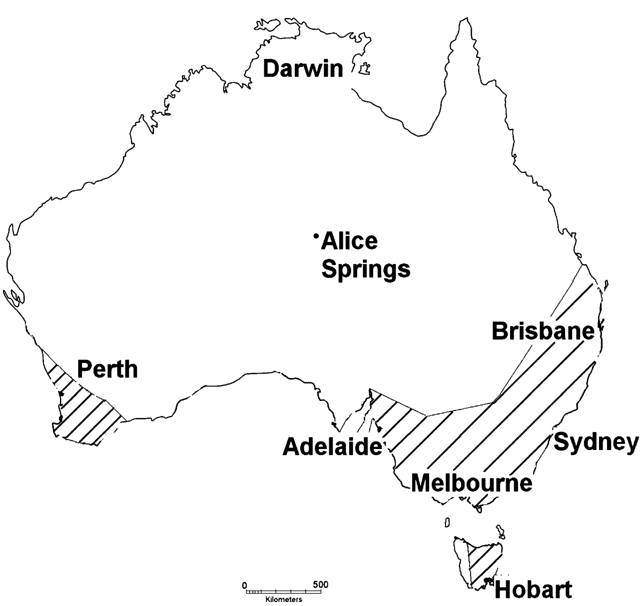


Fig. 1 The temperate regions of Australia

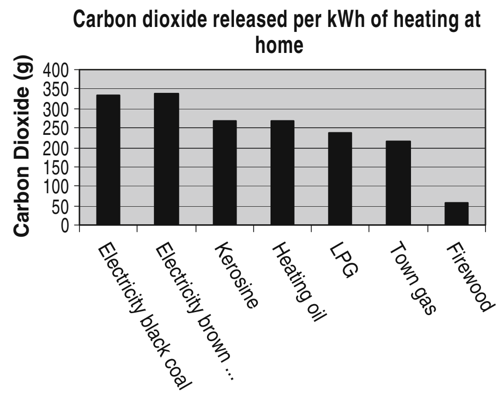


Fig. 2 The amount of carbon dioxide released by burning selected fuels to produce 1 kWh of heating energy. (National Greenhouse Account Factors, Department of Climate Change 2008)

2 Energy sources for home heating

2.1 Electricity

The use of electricity for home heating is convenient and clean since there are no pollutants emitted in the home. Electricity in Australia is largely generated by burning fossil fuels as shown in Table 1.

The main issue with using electric energy for heating is its low efficiency in the process of conversion from heat to electric energy at the power stations.

2.2 Gas

Gas is a convenient and relatively inexpensive form of home heating but has the disadvantage of drawing oxygen from inside the home and, commonly, also releasing its exhaust gases into the home. In the area of concern, gas is mainly bottled liquefied petroleum gas (LPG) sometimes called propane, which must be delivered to the home periodically.

2.3 Wood

Wood burning for home heating is attractive to many people because it is inexpensive relative to other forms of heating and because a burning fire creates a desirable atmosphere. Most firewood comes from Eucalyptus trees on private property (about 84% according to Driscoll et al. 2000), and the rest from public lands such as forestry

Table 1 Percentage of electric energy from various sources for Australia (ABARE 2008)

Source	Australian percentage
Black coal	52.8
Brown coal (lignites)	21.0
Gas	15.0
Hydro	7.8
Other (mainly petroleum)	3.4

thinning, etc. In particular, most wood comes from woodlands in the drier and cooler parts of the country. About 5 million tonnes are used in Australia every year with an average of about 3.0 t per household (Driscoll et al. 2000). It typically has an energy content of about 5.3 kWh/kg of dry weight (Paul et al. 2003). Its use does, however, raise several issues, mainly about the impact on aspects of the natural environment.

The issue of most immediacy for the user is that it draws oxygen from inside the home and releases pollutants via the flue. There is evidence that many people in Australia are exposed to excessively high levels of air pollution, both particulate and gaseous, in winter time because of inappropriate operation of wood fires. However, it is also true that with correct operation such as avoiding damp wood and allowing the correct amount of oxygen to produce a hot burn, the quantities of undesirable emissions can be reduced to acceptable levels (Todd 2003).

The collection of firewood from woodlands also has an impact on the biodiversity of the area because of the removal of habitat, although this impact has not been well documented (Spooner et al. 2002; Department of Environment, Water, Heritage and the Arts 2001; Department of Environment and Climate Change 2008). This issue is not covered well by current life cycle assessment techniques and will be neglected in this study by focusing on firewood plantations rather than native woodlands.

Wood, in principal, is a renewable resource. However, most woodlands from which firewood is currently taken consist of older, established trees where growth is slow and therefore take only small amounts of carbon dioxide from the atmosphere. Burning releases the carbon to the atmosphere, with the net effect being a return of carbon to the atmosphere (Paul et al. 2003).

For all these reasons, there is a need for decisions to be made about whether firewood burning is a desirable practice to promote in the context of home heating, and if so, how the supply of wood might be provided. This study will consider the option of specifically growing trees for firewood in plantations on ex-farming land as recommended by Paul et al. (2003).

3 Home heating scenarios

In order to evaluate the environmental impact of various ways of providing home heating, six different scenarios were considered to account for different appliances in which the fuels were used. Most areas of Australia where wood is used for home heating are inland, and some distance from major cities, and in relatively dry climates of less than 700 mm of rain annually; thus, the study considered only this situation.

3.1 Electricity

Electricity is used for heating in relatively simple heating appliances comprising mainly a resistive heating element and an electric powered fan to disperse hot air. The more complex air conditioning systems were not considered here because of the fact that their heating process is similar to the above and the fact that they typically produce much more heat (and more cooling in summer) and so cannot reasonably be compared to the other heating processes being considered. Detailed data for electricity production in Australia is readily available via the databases attached to SimaPro life cycle assessment software, but it comes predominantly from coal-fired power stations. Electricity use impacts were based on Australian averages.

A typical electric heater was assessed for its component parts in order to allow consideration of its manufacture in the life cycle assessment. Most electric heaters are of relatively light construction with the cases commonly made of a plastic material. It was also assumed to have an electric fan using 30 W to circulate the hot air, to have a lifetime of 15 years and that 80% of the steel case and 95% of the copper in the fan motor would be recyclable at end of life. Conversion of electric energy to heat was assumed to be 100% efficient. Supply of electricity to the premises was taken to be in place and have no additional impact.

3.2 Gas

Gas is used for heating typically in a modern gas burner with electronic temperature control and an electric-powered fan to circulate the hot air. There are two versions of heater, free-standing in which the exhaust gases are released into the room and flued heaters in which gases are released outside the home, with the latter being somewhat less energy efficient. Detailed data for heating by LPG is readily available in the SimaPro databases for Australia.

A typical modern gas heater was assessed for its material content. Most gas heaters are of relatively solid construction with steel cases because of the need to enclose burning gas. It was assumed to have an electric fan using 30 W to circulate the hot air, and to have a lifetime of 15 years and that 80% of the steel case and 95% of the copper in the fan motor would be

recyclable at end of life. It was assumed to also have an electronic controller. The flued version was assumed to be 70% efficient and the unflued version 100% efficient (Paul et al. 2003). Supply of gas to the premises was taken to be in 75-kg steel cylinders transported by small truck a distance of 5 km and by bulk transport a distance of 200 km.

3.3 Wood

There are three common types of wood burner being used in Australia, the traditional open fireplaces with a steel enclosure inserted, pot belly stoves and modern wood burners. Consequently, all three types were considered. Typical models of each were assessed for their material content. The modern burners were also assumed to have an electric fan using 30 W to circulate the hot air. It was assumed that their energy efficiencies were 30%, 40% and 70%, respectively (Paul et al. 2003), that they each had a life of 25 years and that 80% of their steel and 95% of their copper content would be recycled at end of life, involving a transport distance of 400 km. The carbon dioxide released by harvest and transport has been allowed for in the model of wood production below and other transport factors accounted for by assuming a transport distance of 100 km.

3.3.1 Wood supply

Species collected for firewood in inland temperate Australia are typically River Red Gum (*Eucalyptus camaldulensis*), Jarrah (*Eucalyptus marginata*), Yellow box (*Eucalyptus melliodora*) and Ironbarks (*Eucalyptus sideroxylon*, *Eucalyptus crebra*) (Driscoll et al. 2000). These are quite slow-growing species that take many tens of years to reach a size where they become a good source of firewood. There is limited detailed knowledge about the rate at which wood grows in these circumstances and its variation with soil type and rainfall. However, Grierson et al. (1992) studied box-ironbark forests in Victoria towards the south of the temperate region and found that biomass accumulates at about 2 t/ha per year for young trees and reduces to zero when the trees are about 60 years old. Zorzetto and Chudleigh (1999) suggest a yield of about 22.5 t of dry wood after 15 years or an average of 1.5 t per year over time. Paul et al. (2003) used an optimistic figure of about 11 t per year of *Eucalyptus cladocalyx* in some of their simulations. These data are summarized in Table 2.

Wong et al. (2000) conducted extensive measurements of tree growth for several eucalypt species in Gippsland, Victoria, and in South Australia, both around Adelaide and in the southeast, both areas towards the southern end of the eastern temperate region but in some cases with significantly higher rainfall than is common. Trials from areas where the rainfall was less than 700 mm per year, where the winter mean minimum temperature in July was less than 3° and where the mean maximum temperature in January was greater than 24 were considered relevant to this study. Soils were mainly sandy but with some clays. *Eucalyptus nutans* after 11 years had reached a volume of about 110 m^3/ha or 6.6 t/ha per year at a density of about 890 trunks/ha (slightly more than 3 m spacing), and *Eucalyptus globulus* volume for the same areas and growing density was about 140 m^3/ha. These data are also summarized in Table 2.

The Queensland Forestry service has also done measurements of some relatively recently planted Eucalypt species in a range of sites over inland Queensland, towards the north of the eastern temperate region and some in very dry areas (Huth and Ryan 2003), and these data are given in Table 2.

Measurements have also been done by the author of average growth on trees planted in the Warwick area in southern inland Queensland, where annual rainfall averages about 665 mm and soil is mostly heavier black or brown clays. These data are also shown in Table 2.

The growth rate is thus very variable and clearly depends on species, soil, climate and probably management. To be realistic, it is wise to be conservative until such time as the higher growth rates can be realized in practice on a large scale. Hence, for the life cycle assessment, two different growth rates have been considered; 2 and 6 t/ha per year.

3.3.2 A model for wood production

When wood is produced, the carbon dioxide removed from the atmosphere may be estimated by considering the molecular weights of carbon and oxygen. Carbon has a molecular weight of 12 and oxygen has one of 32, so for every tonne of carbon used in tree growth, 3.7 t of carbon dioxide is removed from the atmosphere, and 2.7 t of oxygen is released into the atmosphere. If it is assumed that 50% of wood weight is carbon (Richardson 2005), then for every tonne of wood produced, 1.85 t of carbon dioxide is removed from the atmosphere, and 1.35 t of oxygen is released. If it is assumed that 2 and 6 t of wood can be produced per hectare of plantation per year, then the production of 1 t of wood requires the permanent use of 0.5 and 0.17 ha of arable land, respectively. These figures are comparable with those obtained by Paul et al. (2003). However, according to Paul et al. (2003), about 88% of the above ground biomass is in the stem, which would be removed for firewood. The remaining material would remain on the land in the form of braches, bark, etc. Consequently, the amounts of carbon dioxide and oxygen above must be increased in proportion. Paul et al. (2003) also give figures for carbon dioxide released during plantation establishment and during harvest and transport as 0.44 t/ha and 0.05 t per tonne of dry wood, respectively.

Since Australians use about five million tonnes of firewood every year as outlined above, these growth rate

Table 2 Measurements on tree growth in drier regions of temperate eastern Australia

Tree species	Age (years)	Tree spacing (stems/ha)	Density (kg/m^3)	Wood production/ha (t)	Source of data
Box-ironbark native forests	To 60			2.0 when young	Grierson et al. (1992)
Native forests	15			1.5	Zorzetto and Chudleigh (1999)
E. cladocalyx				11.0	Paul et al. (2003)
E. nutans	11	~900	660	6.6	Wong et al. (2000)
Eucalyptus argophloia	28	200	810	4.1	Huth and Ryan (2003)
	33	440		3.3	
	37	700		3.5	
	40	600		0.2	
	16	200		1.7	
E. sideroxylon	9	500	820	1.0	Author
E. argophloia	9	500	810	0.6	
E. crebra	9	400	840	0.5	
Eucalyptus tereticornis	19	~600	780	5.3	
	16	~600		7.1	
	28	~500		3.0	
Eucalyptus dunnii	19	~600	675	9.0	
	30	~500		2.6	

figures mean that between 0.8 and 2.5 million hectares of land would need to be devoted to production if all firewood were to come from plantations.

3.3.3 Emissions from wood burning

Burning wood releases numerous materials into the atmosphere including the carbon dioxide mentioned above. These releases are known to vary with fuel moisture and oxygen supply (Todd 2003), but there is no simple relationship between the variables that is amenable to modelling (Gras et al. 2002). In simple terms, if wood burns slowly because it is starved of sufficient oxygen, then emissions, and particulates specifically, will be greater, and more damage to human health and the broader environment will occur. Two models for the burning of eucalyptus wood were thus constructed using measured data from Gras et al. (2002) by taking mean value plus the standard error and mean value minus the standard error for every species emitted (worse and better cases, respectively). These two scenarios do not represent worst and best cases but do give an indication of the possible variation in outcomes.

4 Life cycle assessment

The above data were then assessed using SimaPro software and where not otherwise mentioned, associated Australian data. The method chosen was Eco-Indicator (99) E since this is commonly used and gives results similar to several other methods.

A functional unit of 15 kWh of heating per winter day was used, based on the assumption of 2.5 hours of heating at 4 kW and 2.5 hours at 2 kW rates. It was assumed that an average of 100 days of heating per year would be required, giving an annual heating requirement of 1.5 MWh.

5 Results

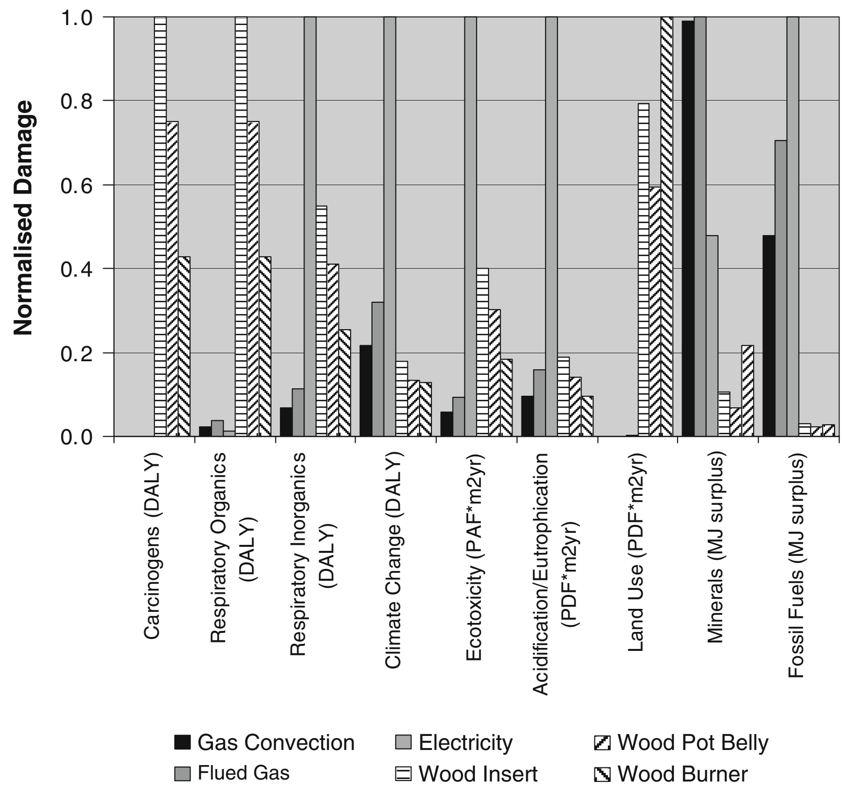
5.1 Overall comparison

A comparison of six different gas, electricity and wood burning heat sources on seven different environmental damage criteria is given in Fig. 3. The wood burners have been chosen to represent typical realistic scenarios.

Using coal-fired electricity can be seen to be much more damaging than all other heating forms on the respiratory inorganics (mainly due to sulphur and nitrogen oxides), climate change (predominantly due to fossil carbon dioxide), ecotoxicity (release of nickel from coal), acidification/eutrophication (nitrogen and sulphur oxides) and fossil fuel usage criteria. Electricity is, however, much better than wood burning on the carcinogen, respiratory organics and land use criteria.

Using gas is more damaging than electricity on the respiratory organics (due to the release of volatile organic compounds) and minerals (copper in the controller), criteria

Fig. 3 Comparison of six different home heating scenarios



with the main difference between the two gas heaters being due to differences in efficiency. Gas is also more damaging than wood burners, due to climate change (carbon dioxide), minerals (copper in controller, not present in wood burners), and fossil fuel (gas) criteria.

Gas, however, is less damaging than wood concerning carcinogens (released from burning wood), respiratory organics (much less volatile organic compound released), respiratory inorganics (wood releases many particulates), ecotoxicity (cadmium from wood) and land use (land for growing wood) criteria.

5.2 Relative impact of wood burner appliances

In order to clarify the relative advantages and disadvantages of the three different types of wood burners currently used, a comparison was done with the assumption that they all used fast, lower emission burning and optimal tree growth (6 t/ha/year) conditions. The comparison is given in Fig. 4.

The data in Fig. 4 show that damage is about inversely proportional to the energy efficiency for most criteria, indicating that the damage comes from the burning of wood rather than from other aspects of the life cycle. However, more efficient appliances use more resources, mainly steel and a fan, and, regarding also the criteria of minerals, there is less difference. The electricity used to power the fan in the modern wood burner also has a significant influence not present in the case of the pot belly stove. However, on balance, it is clear that the more efficient, modern wood burners are far preferable to the older open fire inserts or pot belly stoves.

5.3 The impact of wood growing conditions and wood burning conditions

As discussed above, growing conditions vary significantly requiring different resources to provide the wood from plantations. Similarly, the ways in which the burning fire is managed also has a major impact on the emissions from the fire. In order to evaluate the significance of these differences, four different scenarios were tested in the same appliance, with the results shown in Fig. 5.

From the data in Fig. 5, it can be concluded that the faster burning cases are preferable by a significant ratio varying from about 1.1 to 2, from the point of view of carcinogens, respiratory organics and inorganics, climate change and acidification/eutrophication. These results are due to the fact that burning occurs at a higher temperature. The climate change impact is also affected by the rate of growth of the wood in plantations, while the slower rates require more land with consequentially more energy inputs into establishment, etc.

Slower rates of tree growth also have an impact on the land use criteria, simply because more land is required to produce the wood.

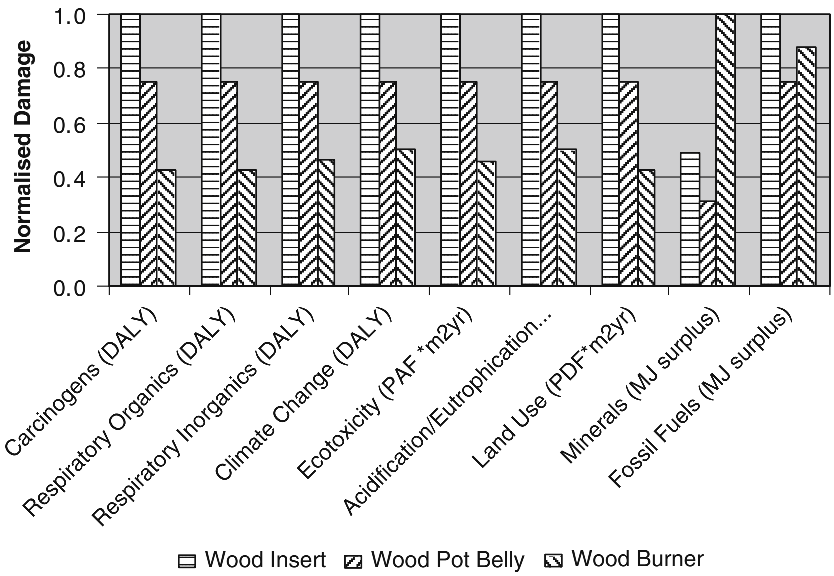


Fig. 4 Comparison of three different wood burning appliances

5.4 Gas or wood?

On the evidence above, it seems that the best choices for home heating are between gas and wood. In order to illustrate both the advantages and disadvantages of each, Fig. 6 shows a comparison of the most optimistic case of each, gas convection and fast burning of wood from a fast growth plantation.

Both gas and wood have significant advantages over the other. Gas is much cleaner from the point of view of emissions because it produces much less damage to human health and ecotoxicity. However, wood is far preferable from a climate

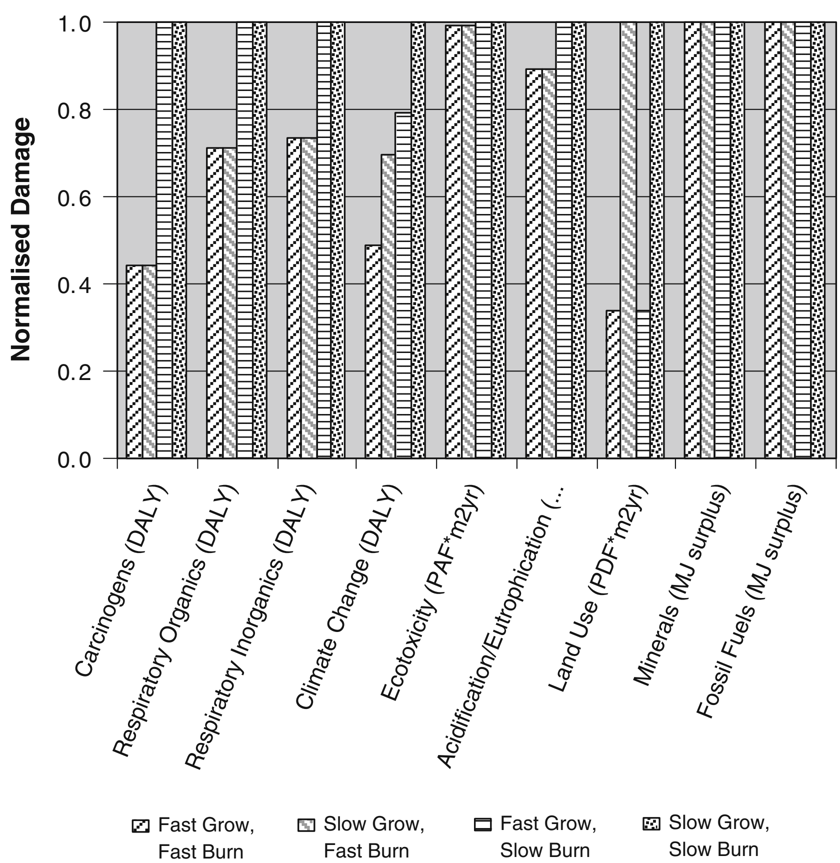


Fig. 5 Comparison of four different wood growth and wood burning conditions

change and fossil fuel point of view, because of its smaller emission of carbon dioxide and the fact that it is essentially a renewable resource. The disadvantage of wood from a land use point of view is probably less significant since there are large areas of land in Australia that could be used to grow firewood.

For the wood burner, the majority of the impacts come from burning the wood with only small contributions of the order of less than 2% coming from the manufacture of the appliance and, in some categories, impacts of the order of 6% from the production of electricity used in the fan. In the case of climate change, the impact is counteracted to the extent of about 87% by the process of growing the wood. The overall impact of recycling the appliance is insignificant.

For the gas burner, the climate change and fossil fuel impact is dominated by the burning of gas with other sources such as transport being less than 1% of that impact. Emissions causing respiratory problems or ecotoxicity are dominated by burning the gas but with significant contributions for the manufacture of the appliance (up to 25%), transport (up to 26%) and electricity use (up to 6%). The impact of recycling was also negligible.

5.5 Comparison with other studies

There appear to be no other published studies on home heating for the climatic situation discussed here. However, it is useful to compare results with those from the much colder climate of Montreal, Canada, where Yang et al. (2008) have reported on two different home heating systems. Their systems were also built in heat distribution systems involving much more material content in the form of boilers, piping, etc., and consequently it is to be expected that the environmental impact would be much greater. However, they also report that the embodied energy is insignificant compared to the operating energy, and their systems heat an entire house, whereas the systems described here are essentially only heating a single room. Comparative figures for greenhouse gas emissions for each of the systems of Yang et al. (2008) using gas as the fuel, and the gas and wood systems discussed in this article are presented in Table 3.

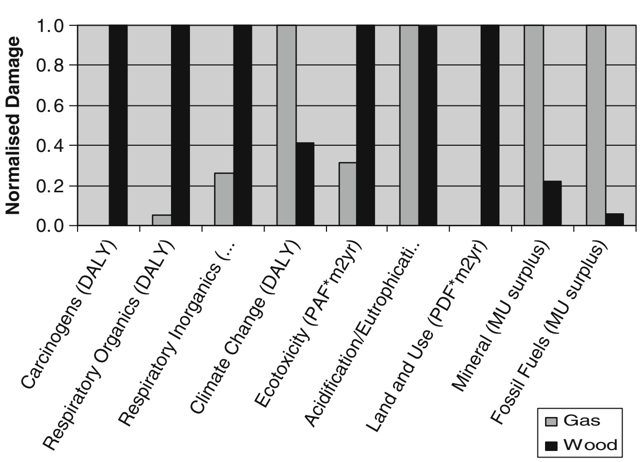


Fig. 6 Comparison of gas and wood heating

Table 3 Comparison of greenhouse gas emissions for Canadian heating systems using gas and Australian room heaters

Heating system	Annual greenhouse gas emissions (kg CO_2 eq.)
Hot water heating	3000
Forced air heating	4967
Gas convection	337
Wood burner	76

Given that the house area heated in the Canadian study was 310 m^2, and a typical room size in Australia might be 25 m^2, a factor of about 12 times, the emissions are similar on a per area basis for gas-fired heaters, but significantly less for the wood-fired heaters.

6 Discussion and conclusions

The environmental impact of home heating using electricity and, given the alternatives, open fire insert and pot belly stove wood burners would seem to be too high to encourage their use in any way. This means that the alternatives for temperate inland Australia are gas burners and modern wood burners.

Gas is convenient and a reasonably low emitter but it is a fossil fuel with limited supply and the problem of release of fossil carbon into the atmosphere. It would, however, appear to have a useful place in future heating.

The use of firewood seems likely to continue in the cooler inland areas of Australia for the reasons outlined above. Firewood grows at acceptable rates and is a renewable resource, so its use has the potential to provide a significant proportion of the home heating needs in temperate Australia. It is clear that this requires a plantation industry that does not exist in any significant way at the moment. Its disadvantages lie mainly in its emissions. However these emissions can be significantly reduced by good management and, particularly in smaller regional centres, can probably be reduced to acceptable levels. There is a need, therefore, to both continue educating the community about how to best manage their fires and to encourage the growth of a plantation firewood industry.

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